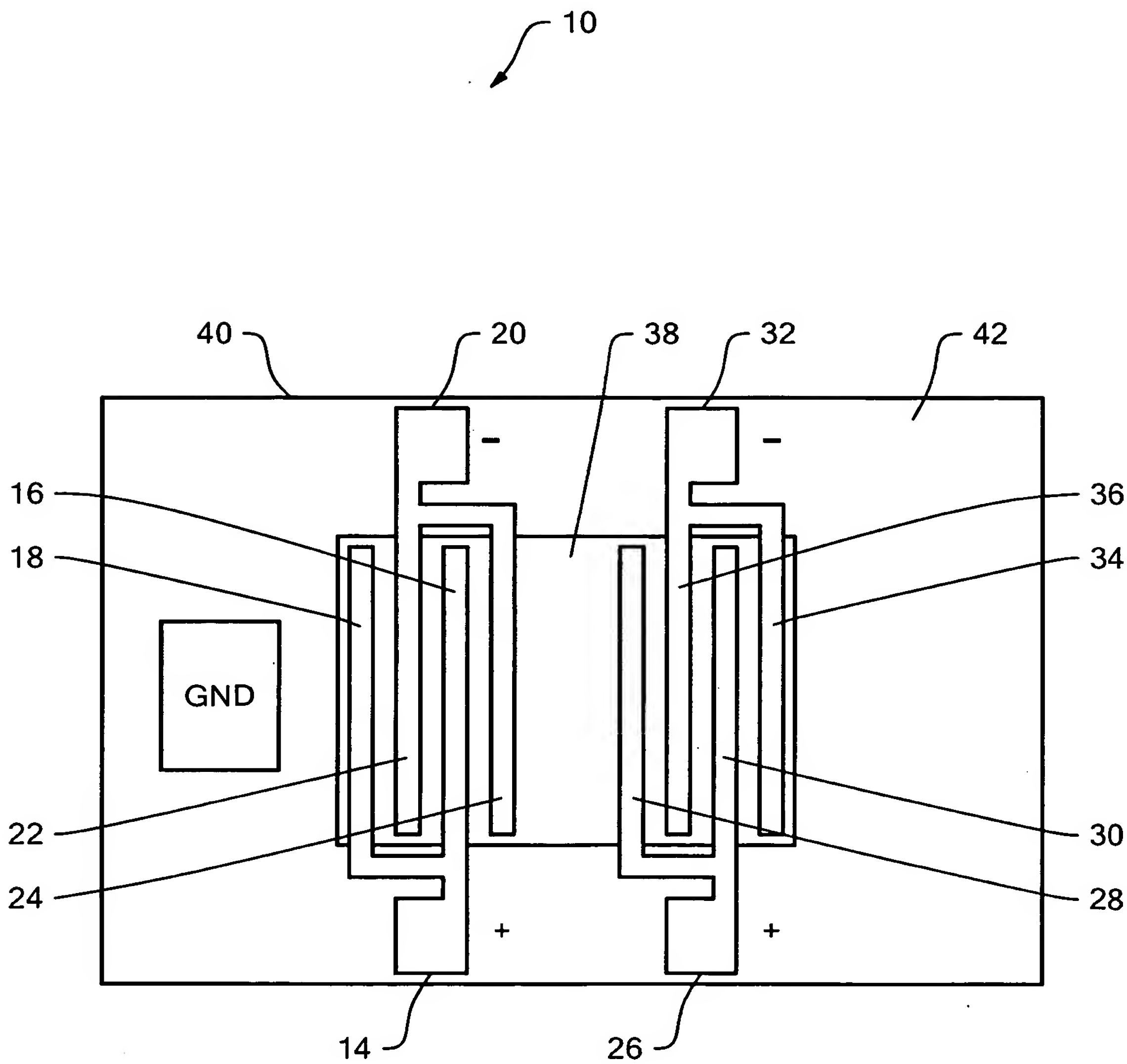


FIG. 1
PRIOR ART

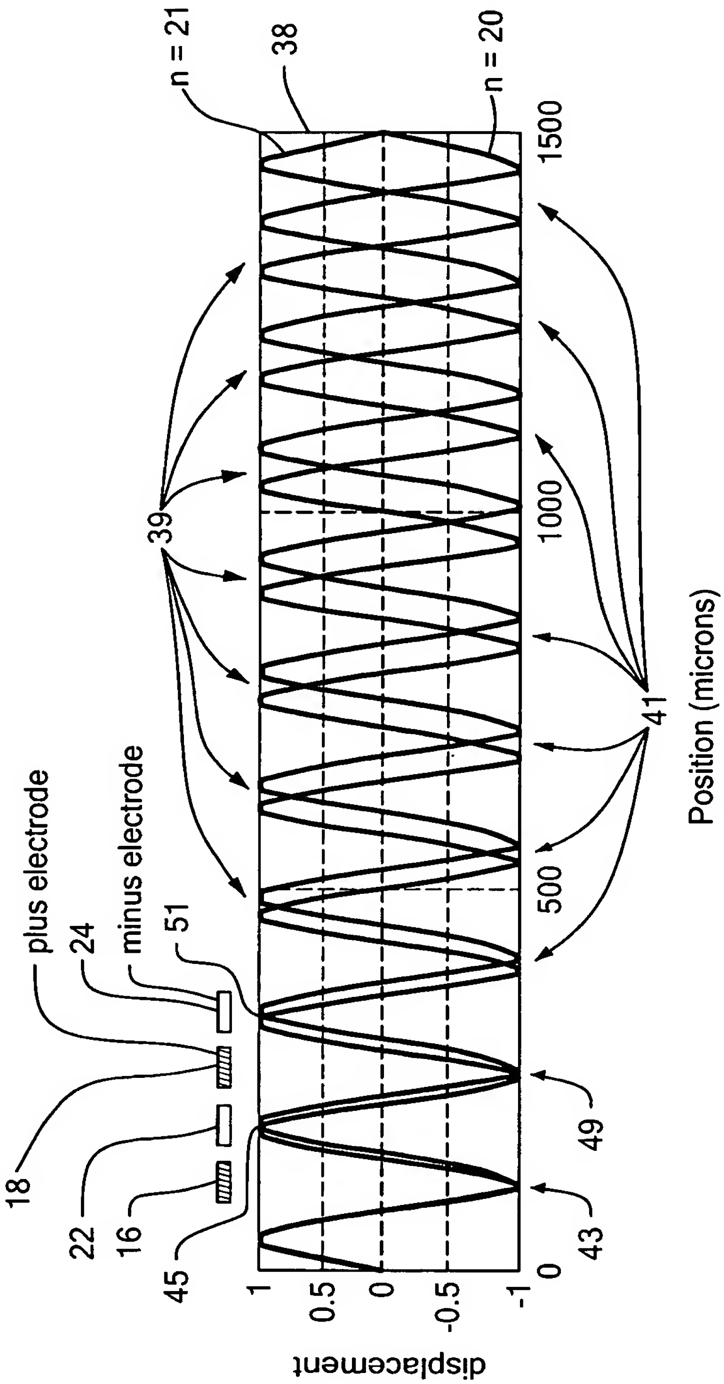


FIG. 2
PRIOR ART

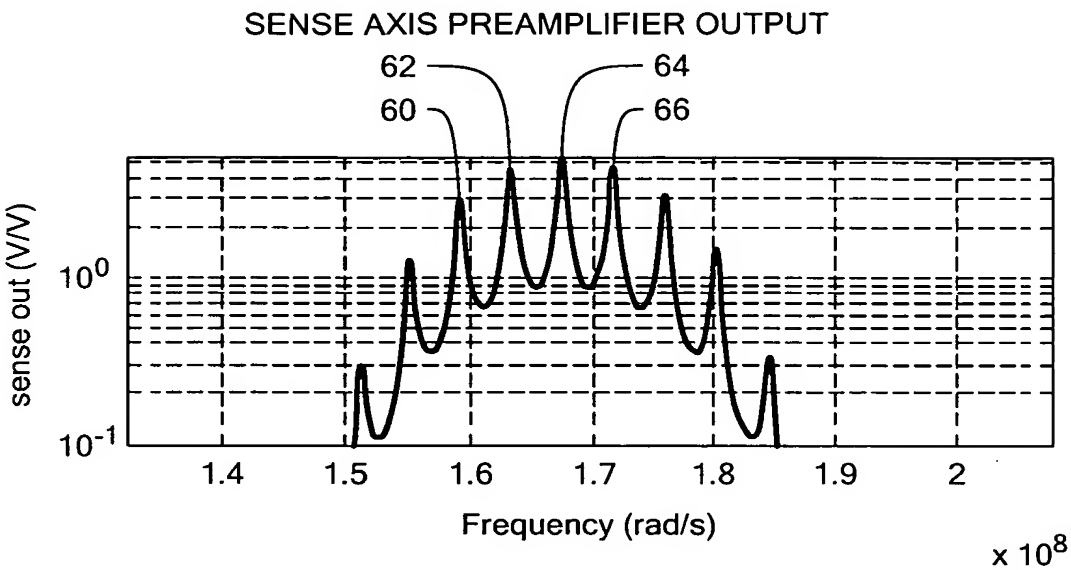

SENSE AXIS PREAMPLIFIER OUTPUT
62
60
64
66
sense out (V/V)
10^0
10^{-1}
1.4
1.5
1.6
1.7
1.8
1.9
2
Frequency (rad/s)
x 10^8

FIG. 3A

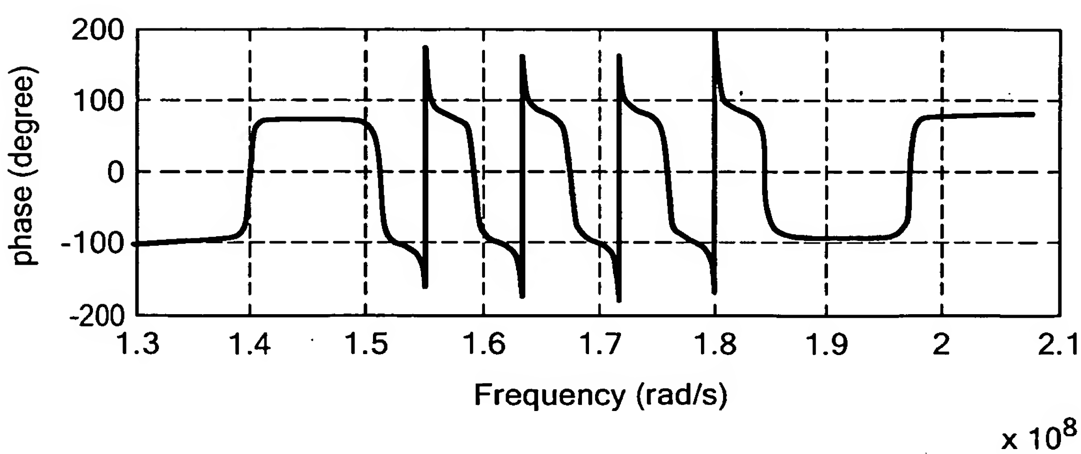

phase (degree)
200
100
0
-100
-200
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
Frequency (rad/s)
x 10^8

FIG. 3B

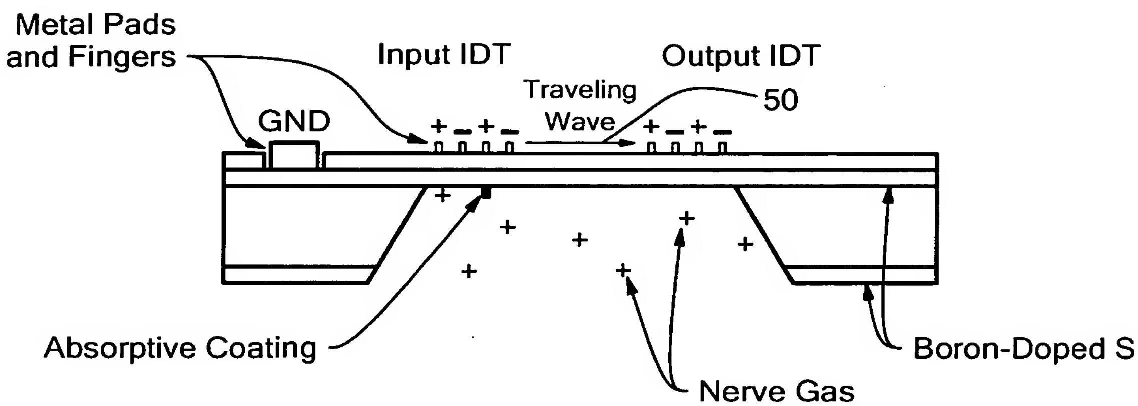


FIG. 4
PRIOR ART

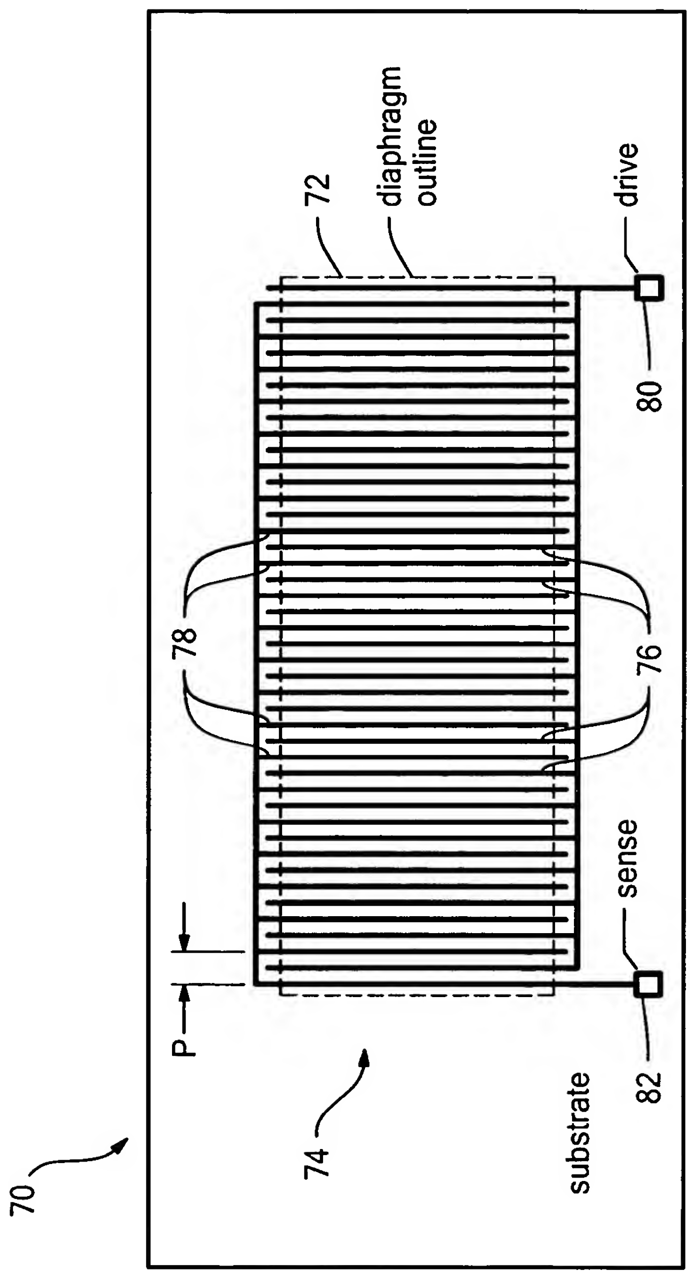

72
diaphragm outline
drive
80
78
76
sense
P
82
74
substrate
70

FIG. 5

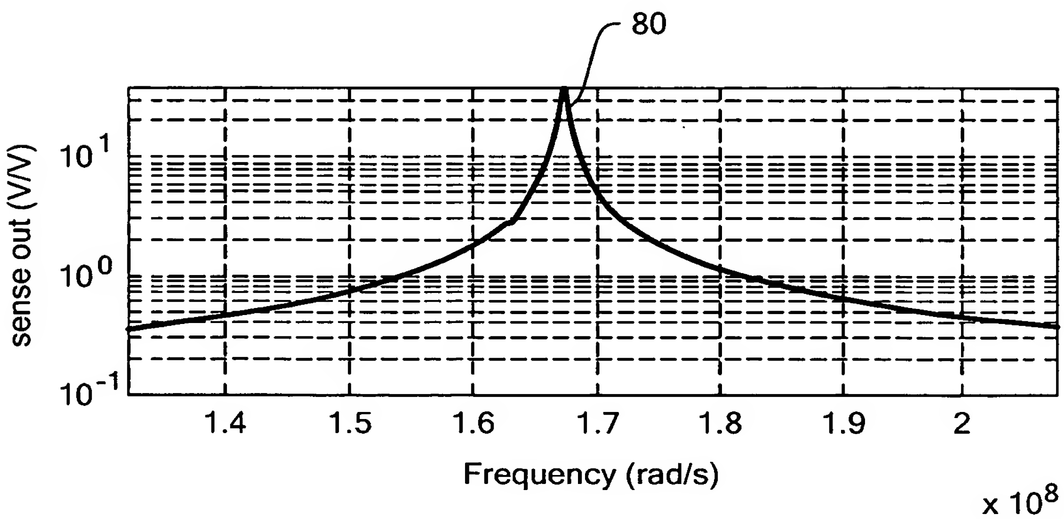

80
sense out (V/V)
10^1
10^0
10^{-1}
1.4
1.5
1.6
1.7
1.8
1.9
2
Frequency (rad/s)
x 10^8

FIG. 6A

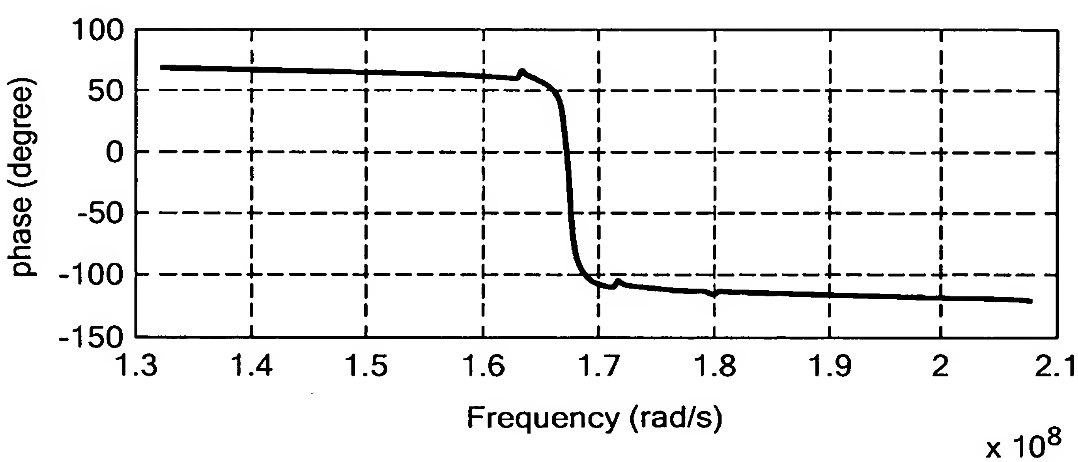

100
50
0
-50
-100
-150
phase (degree)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
Frequency (rad/s)
x 10^8

FIG. 6B

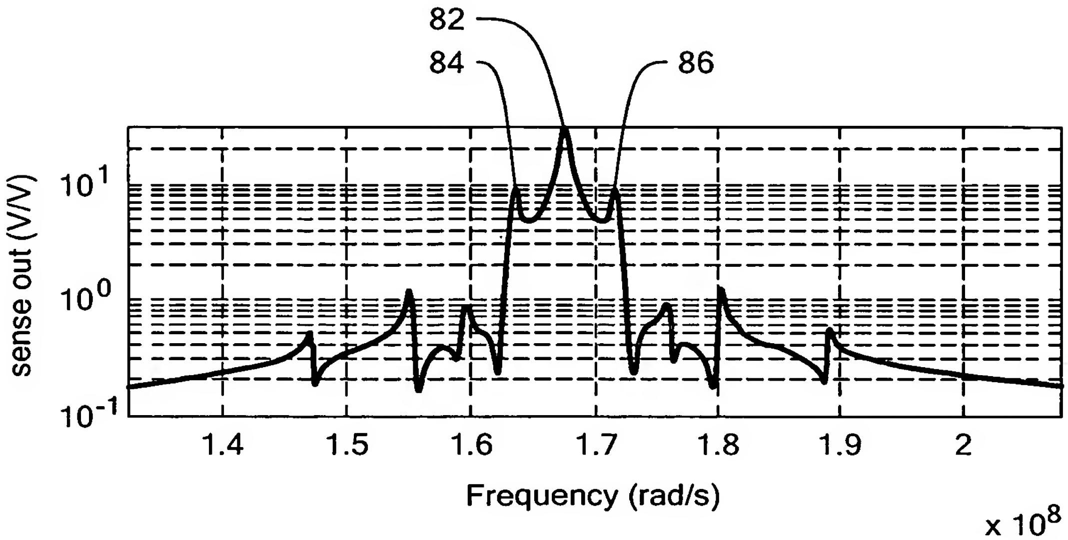

82
84
86
10^1
10^0
10^{-1}
sense out (V/V)
1.4
1.5
1.6
1.7
1.8
1.9
2
Frequency (rad/s)
x 10^8

FIG. 7A

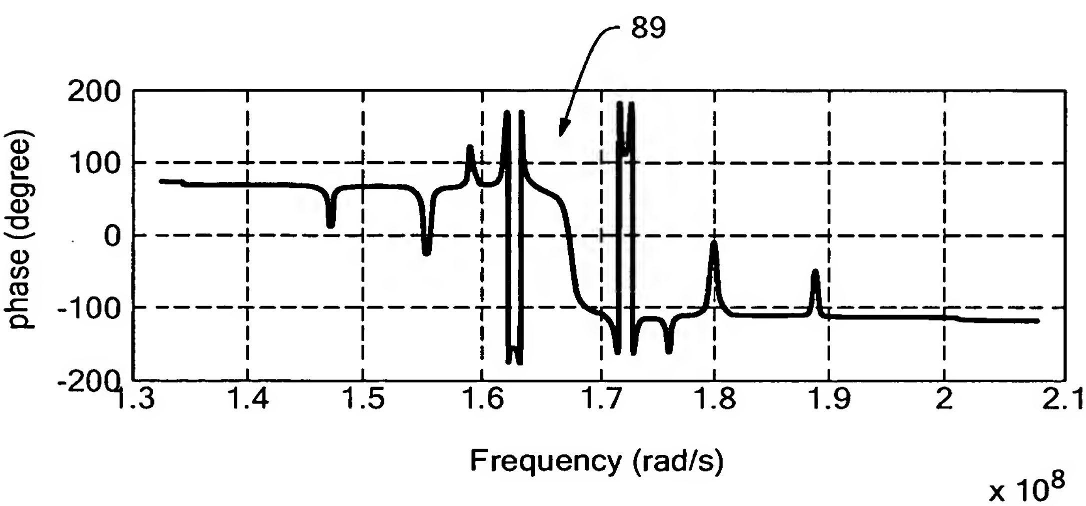

89
200
100
0
-100
-200
phase (degree)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
Frequency (rad/s)
x 10^8

FIG. 7B

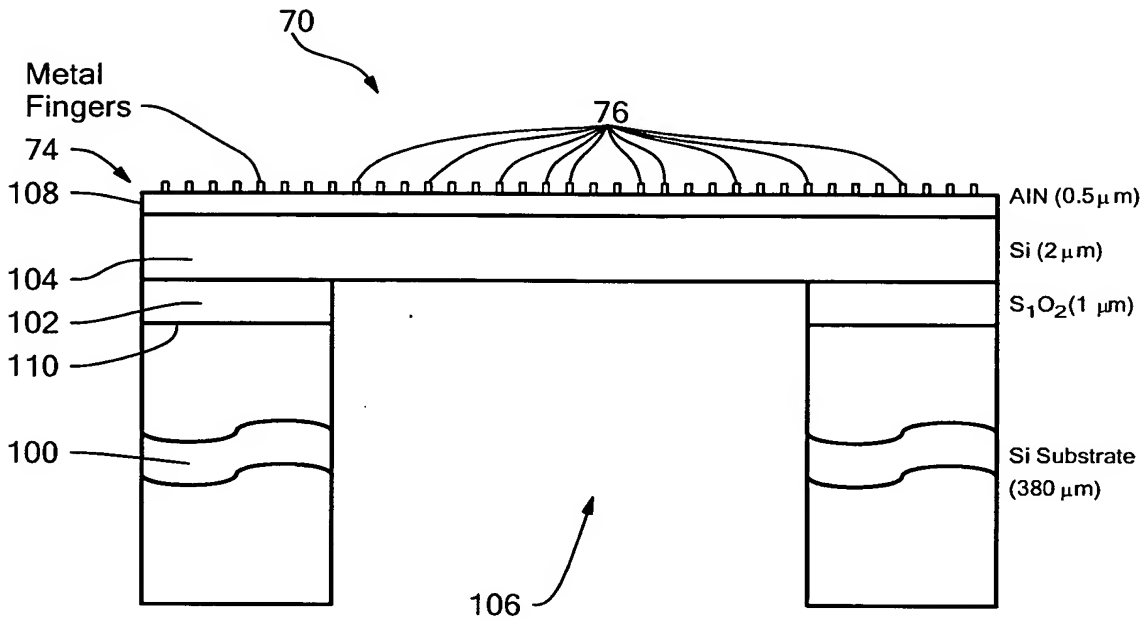

70
Metal Fingers
74
108
76
AlN (0.5μm)
Si (2μm)
104
102
S1O2(1 μm)
110
100
Si Substrate (380 μm)
106

FIG. 8

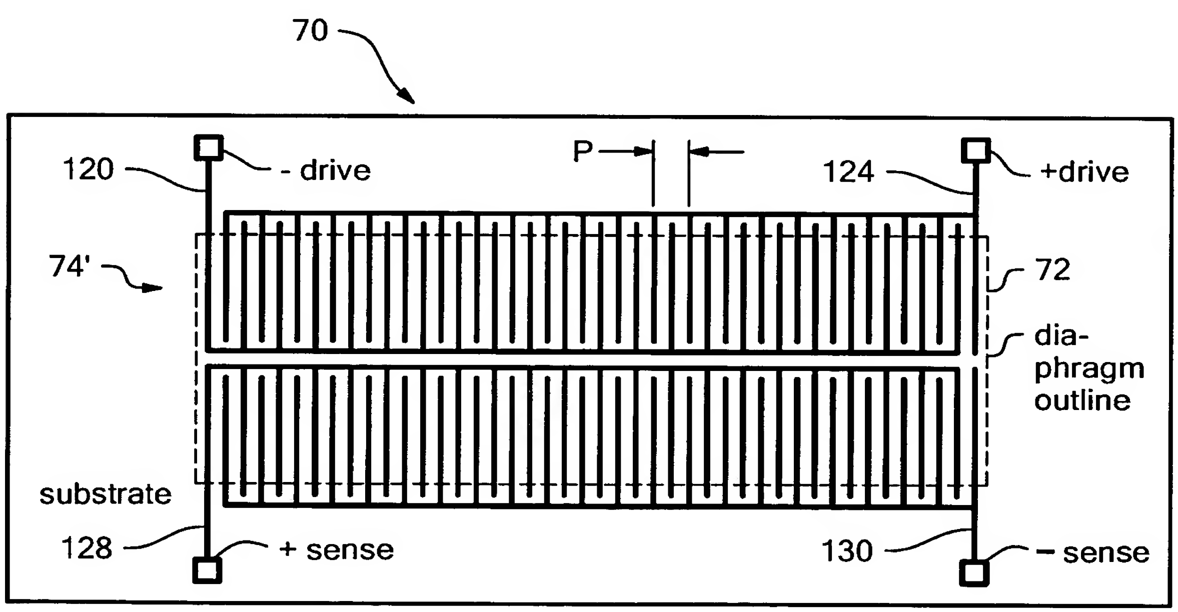
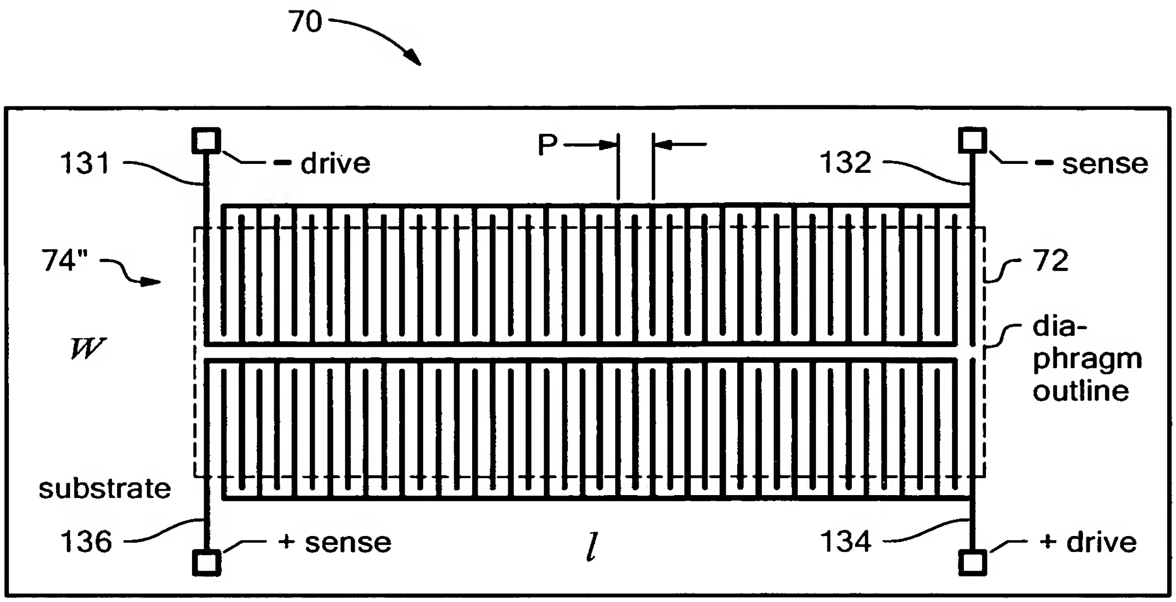

70
120
- drive
P
124
+drive
74'
72
dia-phragm outline
substrate
128
+ sense
130
– sense

FIG. 9



Differential signals-interleaved

FIG. 10

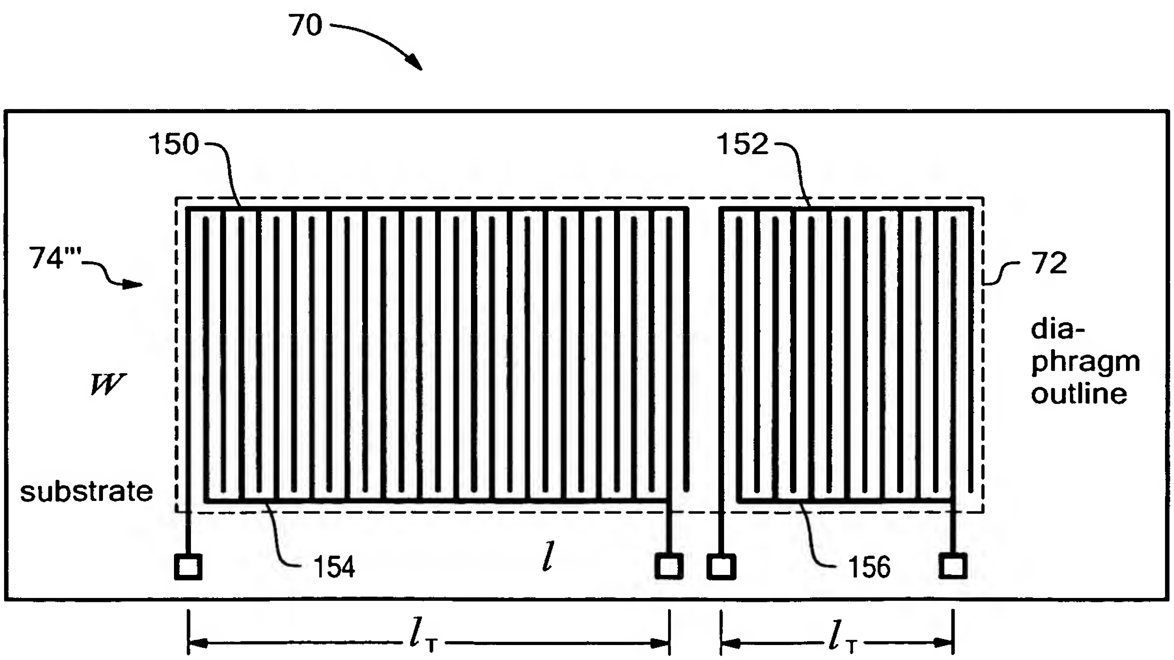


FIG. 11A

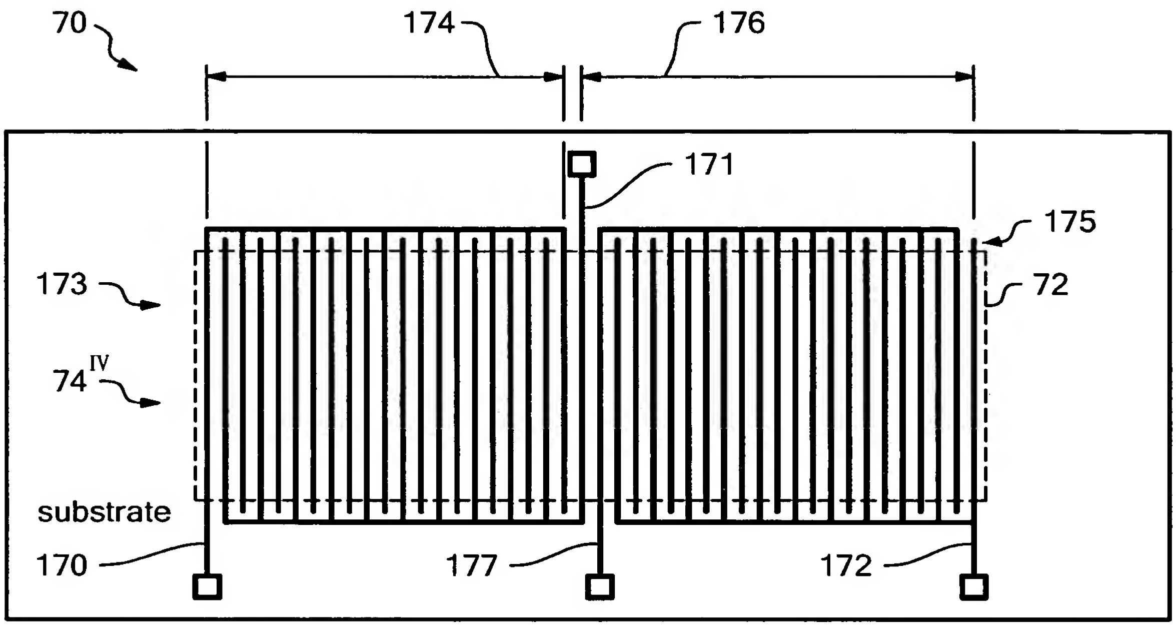


FIG. 11B

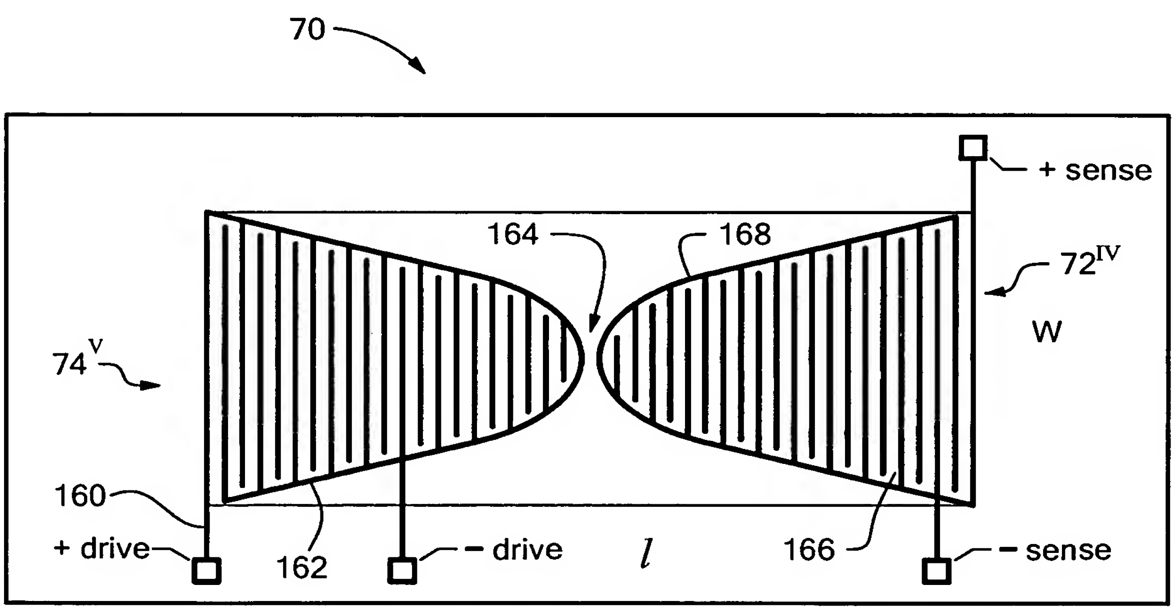


FIG. 12

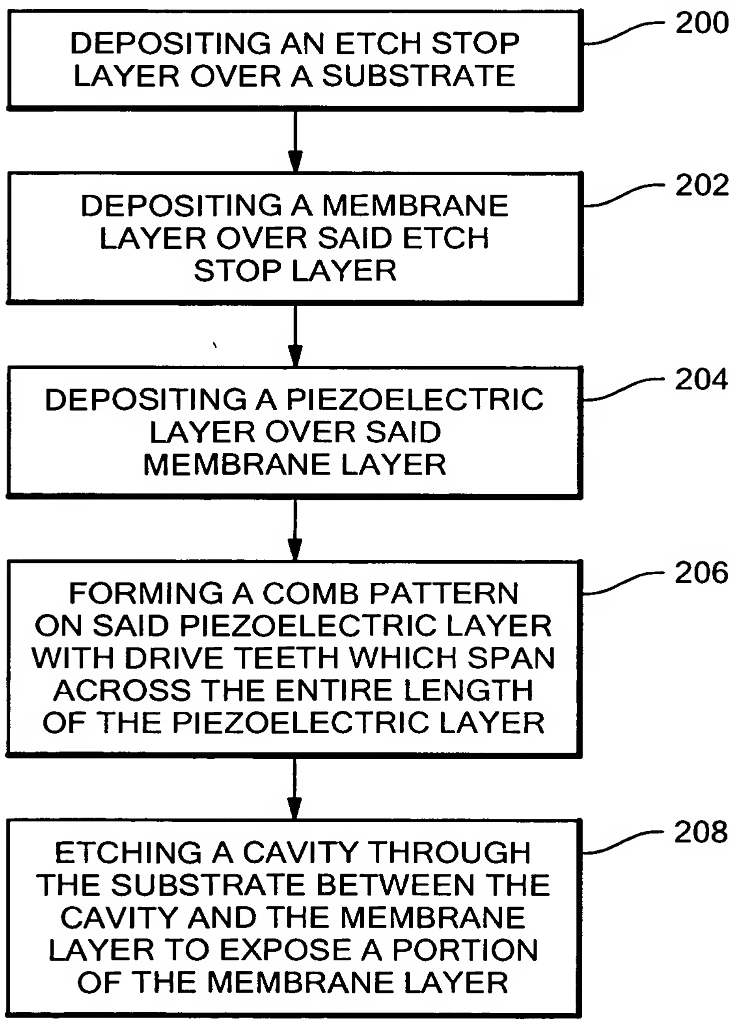

DEPOSITING AN ETCH STOP LAYER OVER A SUBSTRATE
200
DEPOSITING A MEMBRANE LAYER OVER SAID ETCH STOP LAYER
202
DEPOSITING A PIEZOELECTRIC LAYER OVER SAID MEMBRANE LAYER
204
FORMING A COMB PATTERN ON SAID PIEZOELECTRIC LAYER WITH DRIVE TEETH WHICH SPAN ACROSS THE ENTIRE LENGTH OF THE PIEZOELECTRIC LAYER
206
ETCHING A CAVITY THROUGH THE SUBSTRATE BETWEEN THE CAVITY AND THE MEMBRANE LAYER TO EXPOSE A PORTION OF THE MEMBRANE LAYER
208

FIG. 13

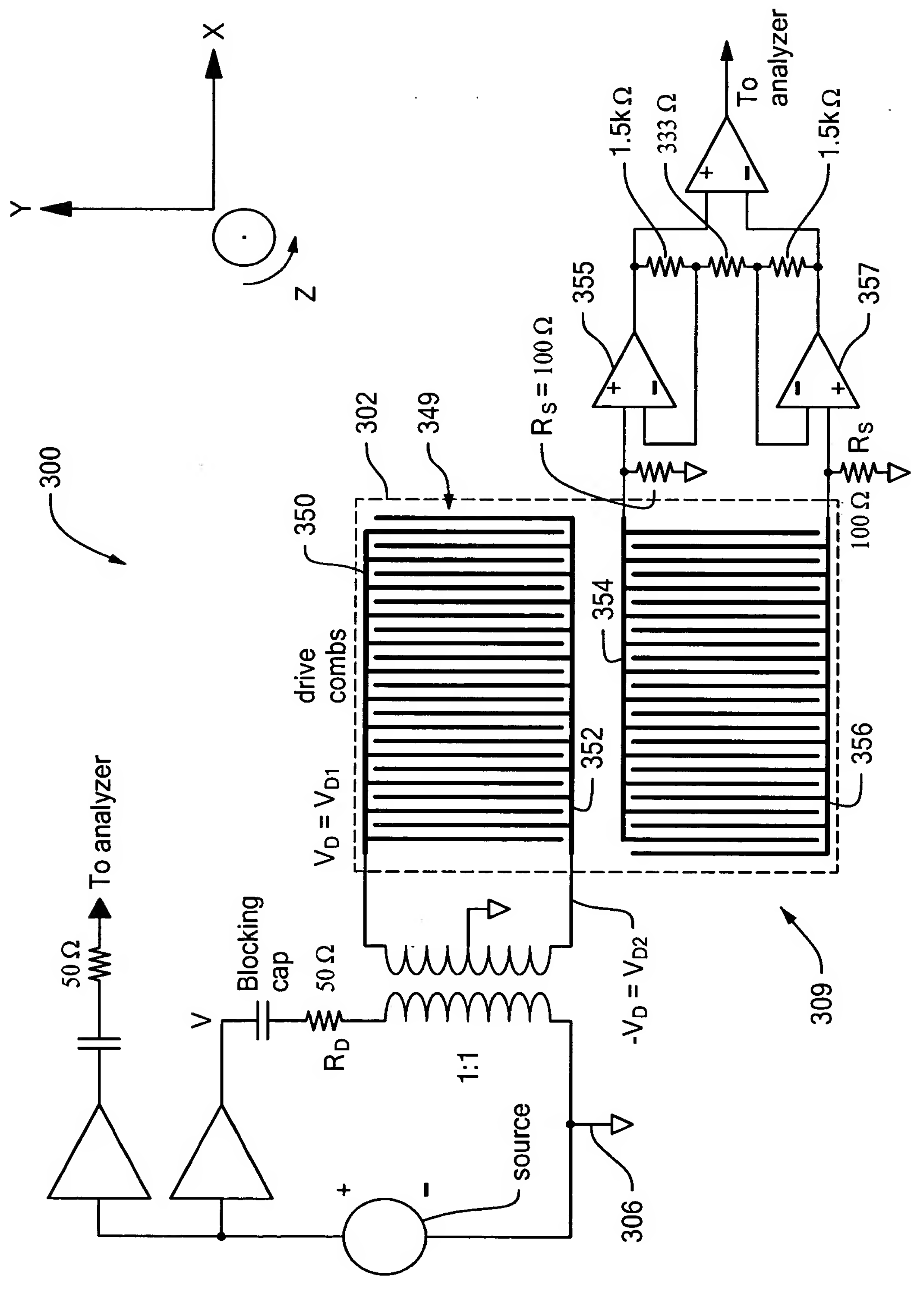

X
Y
Z
300
302
349
350
drive combs
$V_D = V_{D1}$
352
354
356
309
$-V_D = V_{D2}$
306
source
1:1
R_D
50 Ω
Blocking cap
V
50 Ω
To analyzer
$R_S = 100\ \Omega$
355
357
1.5kΩ
333 Ω
1.5kΩ
To analyzer
R_S
100 Ω

FIG. 14

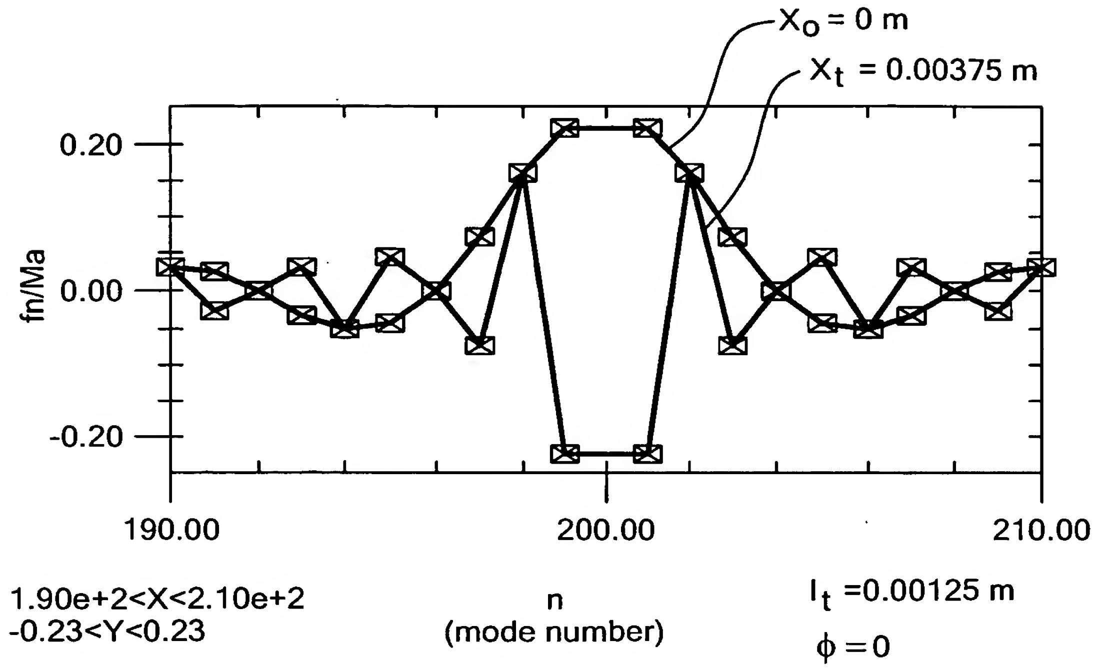


FIG. 15A

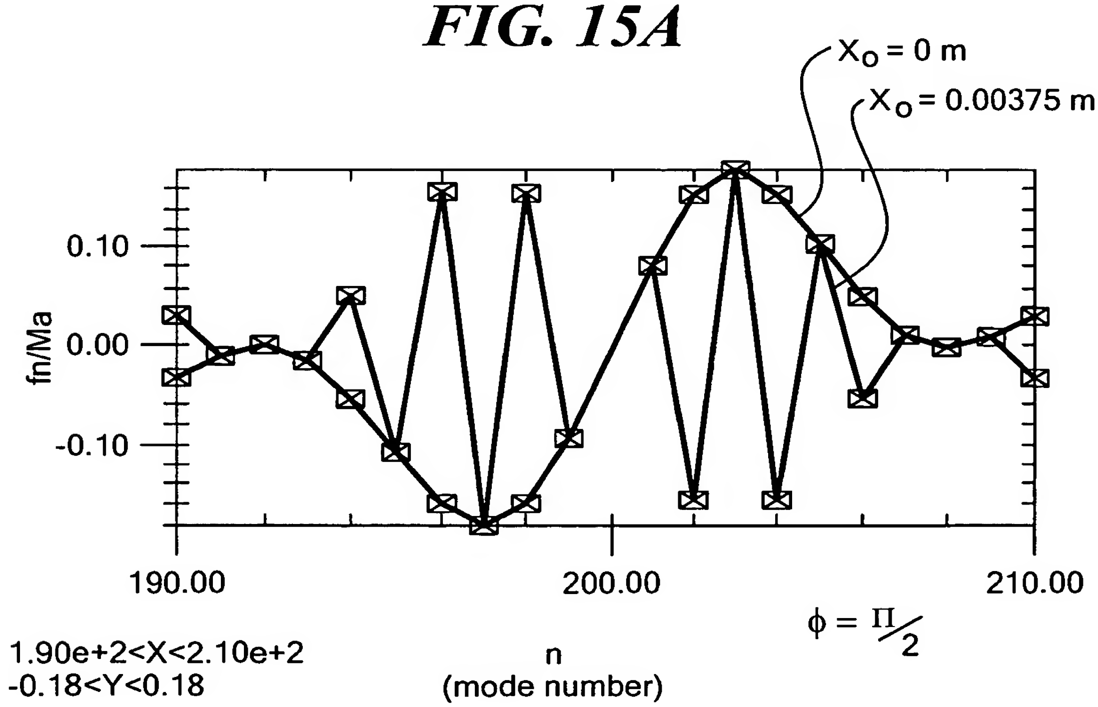


FIG. 15B

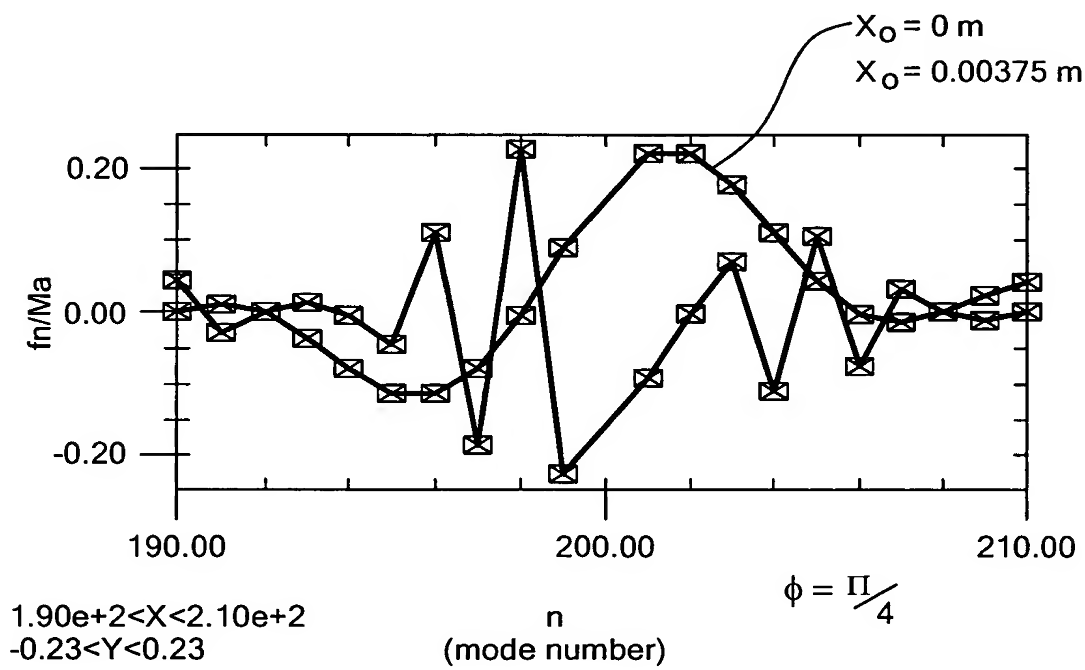

X_O = 0 m
X_O = 0.00375 m
0.20
0.00
-0.20
fn/Ma
190.00
200.00
210.00
$\phi = \Pi/4$
1.90e+2<X<2.10e+2
-0.23<Y<0.23
n
(mode number)

FIG. 15C

```
%MATLAB CODE FOR FPW CHEMICAL SENSOR MODAL FREQUENCY RESPONSE
%
%VARMODEEIG.M  PARAMETERS FOR MICROCANARY
%PLATE WAVE RESONATOR DYNAMIC MODEL
%BASED ON FPW5 EXPANDED TO ARBITRARY NUMBER OF MODES BY ELI WEINBERG 7/19/99
%SEPTEMBER, 1999. CLOSER SCALING AND DIFFERENTIAL SENSE READING ADDED BY MSW.
%SEPARATE DRIVE AND SENSE INPUTS
%FIRST CODED 10/13/97
%   9/20/02 Calculate eigenvalues (photosensitivity investigation) difference from mechanical only
%LATEST RUN 9/20/02

% 11/13/01 ATTEMPT THE CHEMICAL SENSOR Q = 100 CASES
clear, format compact, format short e, i=sqrt (-1);
diary c:\matlab6pl\mw\varmodec.dia
rd = 50/4    %xxx
 %EXTERNAL DRIVE RESISTANCE.  THE FACTOR OF FOUR ACCOUNTS FOR THE N=2
 %TRANSFORMERS AND THE FACT THAT CD IS FOR +/- DRIVE IN PARALLEL.
rs = 100/2    %xxx   %ONE HALF EXTERNAL SENSE RESISTANCE (ohm)
  %THE FACTOR OF  TWO ACCOUNTS FOR CS IS +/- DRIVE IN PARALLEL.
  %GAINS BEFORE SOURCE VOLTAGE IS APPLIED TO FPW
gamp=1  %INPUT AMPLIFIER-BOTH INPUT AND REFERENCE LEGS HAVE SAME GAIN
ginst = 190   %INSTRUMENTATION AMPLIFIER GAIN-
%Completely differential amplifier with 10X second stage
gtran= 0.5    %TRANSFORMER GAIN
%VALUES FOR ALM = 0.5 MICRON, SI = TWO MICRONS
mp=2.47e-6   %xxx MASS PER UNIT LENGTH (KG/M)
dd = 8.781e-11   %STRUCTURAL RIGIDITY (N/M^2)
%q = 400 when bb - 1.033      %xxx               %QUALITY FACTOR
bb = 1.033             %xxx damping (N-s/m^2)
1 = 0.0015       %LENGTH OF DIAPHRAGM (m)
1d = 3.750001E-5*19     %LENGTH OF THE DRIVE TRANSDUCER
1s = 3.750001E-5*19     %LENGTH OF THE SENSE TRANSDUCER
md=38                   %NUMBER OF HALF PERIODS IN TRANDUCER
ms=38                   %NUMBER OF HALF PERIODS IN TRANSDUCER
pd = 2*1d/md            %PITCH OF DRIVE FINGERS (M)
```

FIG. 16A

```
ps = 2*ls/ms          %PITCH OF SENSE FINGERS (M)
%CALCULATE THE MODAL FORCING FUNCTION
phi= 0        %PHASE OF EIGENFREQUENCY (0 FOR PINNED, PI/4 FOR BUILT-IN)
thetad= 0     %PHASE OF TRANSDUCER (radians)
thetas = 0
xd=0      %STARTING POSITION FOR FORCING COMBS
xs=l-ls-xd         %STARTING POSITION OF TRANSDUCER 20
%BEWARE CHANGING XD TO ADJUST TOLERENCES.
%SCALE FACTOR FOR LENGTH OF SENDER OR RECEIVER COMB
%MODEINT IS MSW FUNCTION BASED ON MACSYMA INTEGRATION

nmode=input('Enter number of modes  ')
model=input('Enter number of first mode in model  ')

for c0=1:nmode
   n(c0)=(model-1+c0);
end   %MODE NUMBER, ROUGHLY NUMBER OF HALF WAVE LENGTHS



alph = 0.004874/1.676e5^2
      %piezo coupling coefficient for 100% transducer length (coul/m)
gamm = 9.39e-11*1.676e5^4             %piezo coupling coefficient (m/V)

for c1 = 1:nmode;
     pc(c1,1)=modeint(n(c1),md,l,ld,phi,thetad,xd);
     pc(c1,2)=modeint(n(c1),ms,l,ls,phi,thetas,xs);
     lam(c1)=n(c1)*pi/l; %eigenvalue of plate motion (1/m)
     gammad(c1)=gamm*pc(c1,1)/lam(c1)^4;
     gammas(c1)=gamm*pc(c1,2)/lam(c1)^4;
     alphad(c1)=alph*lam(c1)^2*pc(c1,1);
     alphas(c1)=alph*lam(c1)^2*pc(c1,2);
     wn(c1)=sqrt(dd/mp)*lam(c1)^2;  %eigenfrequency (rad/s)
     damping(c1) = bb;            %mode damping (N-s/m^2)
     k(c1) = mp*wn(c1)^2;             %mode stiffness (N/m^2)
     checkalpha(c1) = 1-gammad(c1)*k(c1)*0.5*1/alphad(c1);
```

FIG. 16B

```
end
pc,wn,gammad,gammas,alphad,alphas,checkalpha

cs = 7.567e-11*ls/l   %CAPACITANCE FROM SENSE COMBS TO GROUND, 2 POLES (F)
                      %EQUAL TO THAT CALCULATED IN TABLE 1. STRAYS MAY ADD MORE.
cd = 7.567e-11*ld/l                  %DRIVE CAPACITANCE (F)
rfb=rs*ginst          %SENSE AXIS RESISTOR AND INSTRUMENTATION AMPLIFIER

%ENTER THE COEFFICIENTS OF THE DERIVATIVES
%STATES ARE [QD,QS,V1,X1,V2,X2,V3,X3]
ml=zeros(2+2*nmode, 2+2*nmode);
mra=zeros(2+2*nmode, 2+2*nmode);
ml(1,1)=(cd*rd);
ml(2,2)=cs*rs;
mra(1,1)=-1;
mra(2,2)=-1;

for c2=1:nmode
    ml(2*c2+1, 2*c2+1)=mp;
    ml(2*c2+2, 2*c2+1)=1;
    ml(2*c2+1, 1)=rd*k(c2)*gammad(c2);
    ml(2*c2+1, 2)=rs*k(c2)*gammas(c2);

    mra(2*c2+1, 2*c2+1)=-damping(c2);
    mra(2*c2+1, 2*c2+2)=-k(c2);
    mra(2*c2+2, 2*c2+1)=1;
    mra(1, 2*c2+2)=alphad(c2);
    mra(2, 2*c2+2)=alphas(c2);
end

 %ENTER COEFFICIENTS OF DRIVE VOLTAGE
mrb=zeros(2*nmode+2, 1);
mrb(1)=cd;
for c3=1:nmode
    mrb(2*c3+1)=k(c3)*gammad(c3);
end
```

FIG. 16C

```
%ml, mra, mrb

%SET UP THE STATE MATRICES
invml=inv(ml);
checkinvml=invml*ml
a=invml*mra
b=invml*mrb
[evec,eval]=eig(a);
damp(eval)
%eval
%evec

%PICK OUT THE DIFFERENCE IN THE EIGENFREQUENCIES
yy=sort(damp(eval)); %PLACE THE EIGENVALUES IN ORDER. CHECK THAT THE POLES CORRESPONDING TO THE
                     %RC ARE HIGHER THAN THE MECHANICAL POLES
for ii = 1:nmode
     wncl(ii)=yy(2*ii-1);  %MAKE THE VECTORS OF DIFFERENT LENGTHS SIMILAR AND OMIT THE TWO FASTEST POLES
end
wndiff=wncl-wn       %SHIFT FROM MECHANICAL RESONANCES TO CLOSED LOOP

%OUTPUTS ARE AMPLITUDE,SENSE PREAMPLIFIER OUTPUT, AND INPUT CHARGE THROUGH RD
%WITH GIN = 1 INPUT IS INPUT TO 10X AMPLIFIER WHICH IS MEASURED BY
%ANALYZER
gin = 1    %SOURCE TO PREAMP INPUT
c=zeros(3, 2+2*nmode);
for c4=1:nmode
    c(1, 2*c4+2)=1;
    c(2, :)=a(2, :)*rfb;
    c(3, 1)=.5;
    end
c=c*gamp*gtran*gin
d=[0;b(2,:)*rfb; 0]*gamp*gtran*gin
%w=logspace(7,9,200);
```

FIG. 16D

FIG. 16E

```
nw=1001
dw=(1.1*wn(nmode)-0.9*wn(1))/(nw-1);
w=[0.9*wn(1):dw:1.1*wn(nmode)];
wmax=w(length(w))
[m1,p1]=unbode(a,b,c,d,1,w);
xmax = max(m1(:,1))
vmax = max(m1(:,2))
figure(1),clf,subplot(2,1,1)
semilogy(w,m1(:,2)),grid,xlabel('frequency (rad/s)')
ylabel('sense out (V/V)'),axis([w(1),wmax,0.01,max(m1(:,2))])
title('SENSE AXIS PREAMPLIFIER OUTPUT')
subplot(2,1,2)
plot(w,p1(:,2)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
figure(2),clf,subplot(2,1,1)
semilogy(w,m1(:,1)),grid,xlabel('frequency (rad/s)')
ylabel('amplitude (m/V)'),axis([w(1),wmax,0.01*max(m1(:,1),max(m1(:,1))])
title('MOTION AMPLITUDE')
subplot(2,1,2)
plot(w,p1(:,1)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
figure(3),clf,subplot(2,1,1)
semilogy(w,m1(:,3)),grid,xlabel('frequency (rad/s)')
ylabel('charge (C/V)')
title('DRIVE CHARGE')
subplot(2,1,2)
plot(w,p1(:,3)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
%[z,p,k,]=ss2zp(a,b,c,d,1) %OBTAIN THE POLES AND ZEROS OF TRANSFER FUNCTION
diary off
```

```
function [pc]=modeint(n,m,l,lt,phi,theta,xo);
%FUNCTION TO OBTAIN THE MODAL FORCING FUNCTION NORMALIZED TO ONE
%DERIVED BY MACSYMA AND CODED 10/20/97
pc = -lt*sin(((pi*lt*n+pi*l*m)*xo-l*lt*theta-l*lt*phi+pi*lt^2....
      *n+pi*l*lt*m)/(l*lt))/(pi*(lt*n+l*m))+lt*sin(((pi*lt*n+.....
      pi*l*m)*xo-l*lt*theta-l*lt*phi)/(l*lt))/(pi*(lt*n+l*m))+lt*....
      sin(((pi*lt*n-pi*l*m)*xo+l*lt*theta-l*lt*phi+pi*lt^2*n-pi.....
      *l*lt*m)/(l*lt))/(pi*(lt*n-l*m))-lt*sin(((pi*lt*n-pi*l*m)*......
      xo+l*lt*theta-l*lt*phi)/(l*lt))/(pi*(lt*n-l*m));
```

FIG. 16F

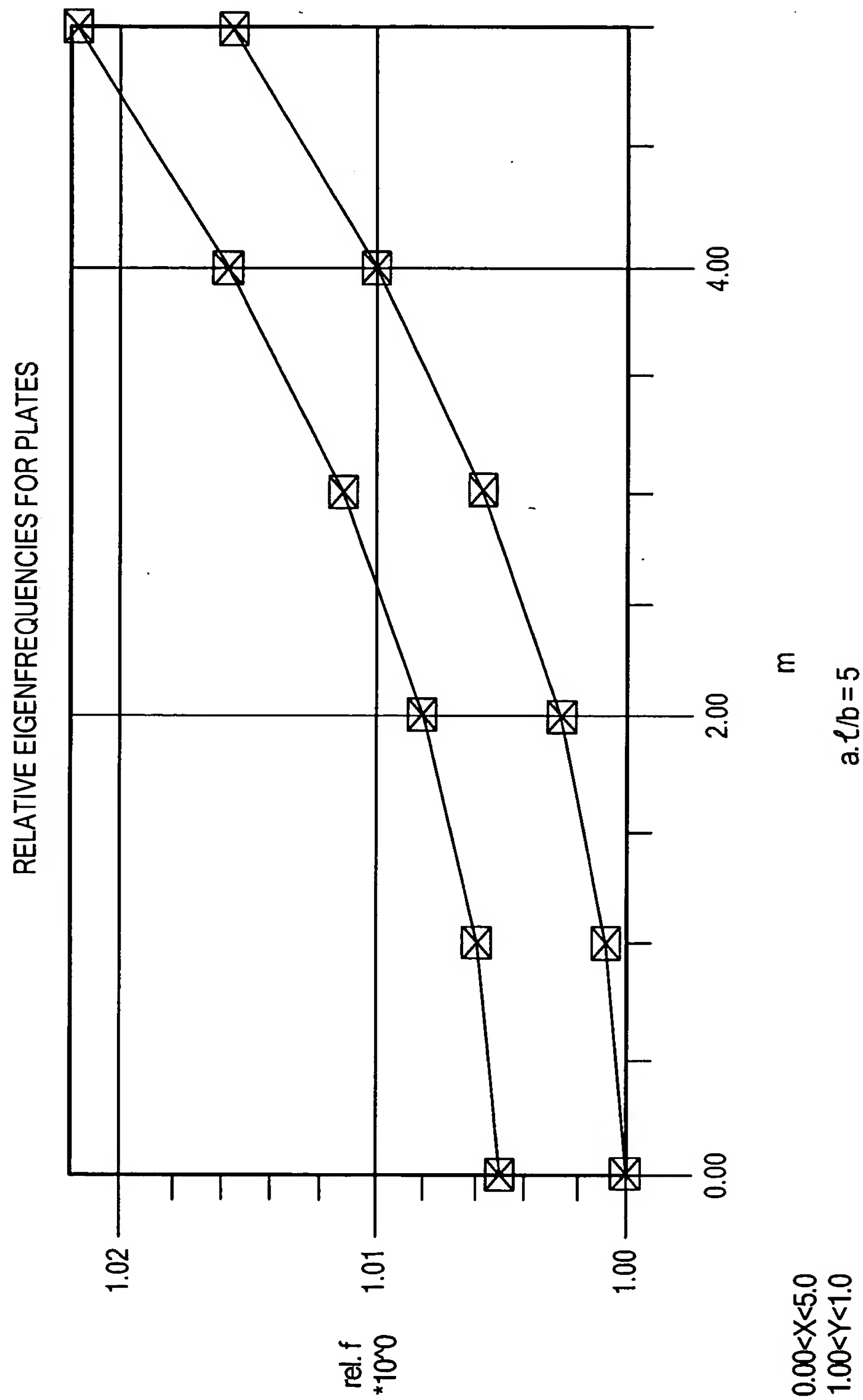

RELATIVE EIGENFREQUENCIES FOR PLATES
1.02
1.01
1.00
rel. f
*10^0
0.00
2.00
4.00
m
a.ℓ/b=5
0.00<X<5.0
1.00<Y<1.0

FIG. 17

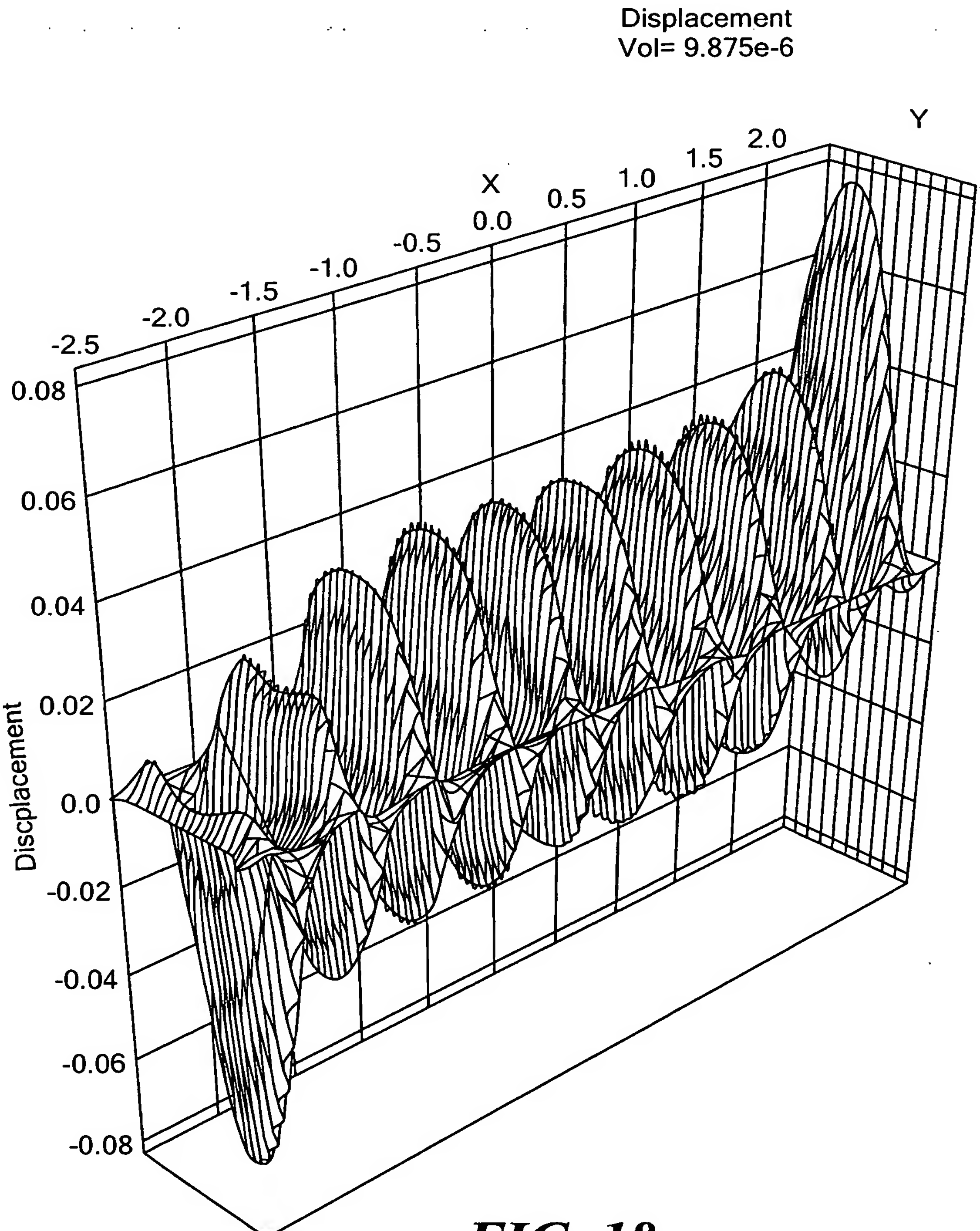


FIG. 18

Static Plate Deflections
for Sinusoidal Load